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# Analysis of the Nonlinear Density Wave Two-Phase Instability in a Liquid Metal Reactor Steam Generator

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## 1. Introduction

The KALIMER-600 being developed at KAERI employs an once-through helically coiled steam generator. The helically coiled steam generator is compact and is efficient for heat transfer, however, it suffers from the two-phase instability. It is well known that the density wave instability is the main source of instability among various types of instabilities in a helically coiled S/G in a LMR. In the present study a simple method for analysis of the density wave two-phase instability in a liquid metal reactor S/G is proposed and the method is applied to the analysis of density wave instability in a 50MWt S/G at JAEA where the experimental data are available.

## 2. Analysis

The present method is formulated with control volumes with moving boundaries and the homogeneous equilibrium flow model is used in the two-phase region. The governing equations for the calculation domain shown in Fig.1 are as follows;

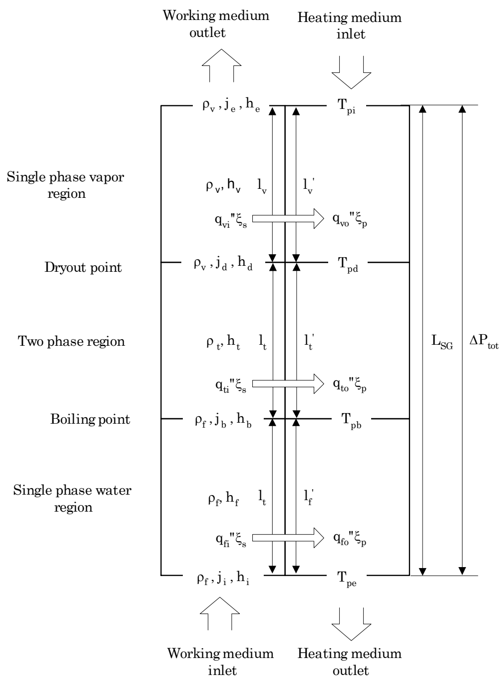



Fig.1 Calculation domain and parameters

2.1 Primary side

$$\dot{m}_p(C_{pi}T_{pi} - C_{pd}T_{pd}) = q''_{vo}\xi_p l_v \quad (1)$$

$$\dot{m}_p(C_{pd}T_{pd} - C_{pb}T_{pb}) = q''_{to}\xi_p l_t \quad (2)$$

$$\dot{m}_p(C_{pb}T_{pb} - C_{pe}T_{pe}) = q''_{fo}\xi_p l_f \quad (3)$$

where

$$q''_{fo} = h_{fo}\frac{(T_{ep} - T_{is}) - (T_{bp} - T_{bs})}{\ln[(T_{ep} - T_{is})/(T_{bp} - T_{bs})]} \quad (4)$$

$$q''_{to} = h_{to}\frac{(T_{bp} - T_{bs}) - (T_{dp} - T_{ds})}{\ln[(T_{bp} - T_{bs})/(T_{dp} - T_{ds})]} \quad (5)$$

$$q''_{vo} = h_{vo}\frac{(T_{ip} - T_{es}) - (T_{dp} - T_{ds})}{\ln[(T_{ip} - T_{es})/(T_{dp} - T_{ds})]} \quad (6)$$

2.2 Secondary side

(1) Sub-cooled region.

$$\rho_f\frac{d}{dt}(l_f) = \rho_i j_i - \rho_b j_b \quad (7)$$

$$\rho_f\frac{d}{dt}(l_f h_f) = \rho_i j_i h_i - \rho_b j_b h_b + \frac{q''_f\ \xi_s\ l_f}{A_s} \quad (8)$$

(2) Boiling region.

$$\rho_t\frac{d}{dt}(l_t) = \rho_b j_b - \rho_d j_d \quad (9)$$

$$\rho_t\frac{d}{dt}(l_t h_t) = \rho_b j_b h_b - \rho_d j_d h_d + \frac{q''_t\ \xi_s\ l_t}{A_s} \quad (10)$$

(3) Dry out region.

$$\rho_v\frac{d}{dt}(l_v) = \rho_d j_d - \rho_e j_e \quad (11)$$

$$\rho_v\frac{d}{dt}(l_v h_v) = \rho_d j_d h_d - \rho_e j_e h_e + \frac{q''_v\ \xi_s\ l_v}{A_s} \quad (12)$$

The momentum equation is given as follows;

$$\Delta P_{ext} = \frac{d(\rho_f j_f)}{dt}l_f + \frac{d(\rho_t j_t)}{dt}l_t + \frac{d(\rho_v j_v)}{dt}l_v + \rho_e j_e^2 - \rho_i j_i^2$$
$$+ g(\rho_f l'_f + \rho_t l'_t + \rho_v l'_v) + \frac{\xi_s}{A_s}(\tau_{wf}l_f + \tau_{wt}l_t + \tau_{wv}l_v) + \frac{1}{2}k_i\rho_i j_i^2 \quad (13)$$

The details of the governing equations are given in Choi [1] and are not reproduced here.

## 3. Results and Discussion

The proposed method is applied to the analysis of density wave instability in a 50MWt S/G at JAEA. Fig.1 shows six cases of steady solution with experimental data. We observe the code is accurate enough to be used in the engineering purpose. Fig.3 shows the size of three regions according to the mass flow rate. Fig.4 shows the pressure drop according to mass flow rate. They follow the general shape given in the literature, especially when the mass flow rate is greater than 15kg/sec.

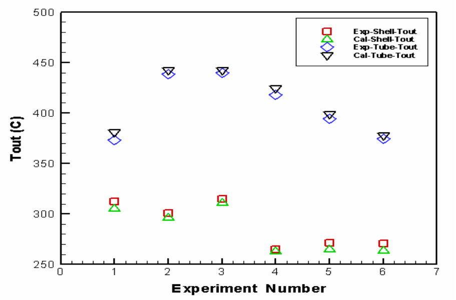



Fig.2 Validation of code

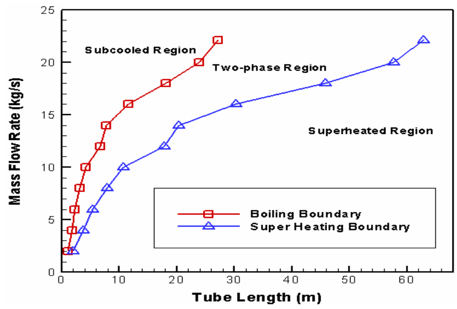



Fig.3 Sizes of regions

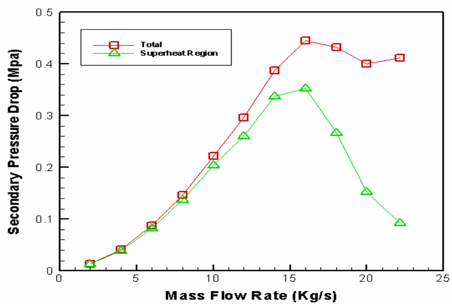



Fig.4 Secondary pressure drop

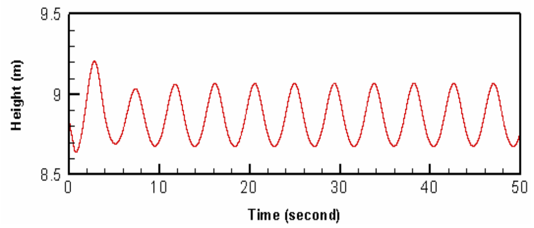



Fig.5 Temporal variation of boiling boundary

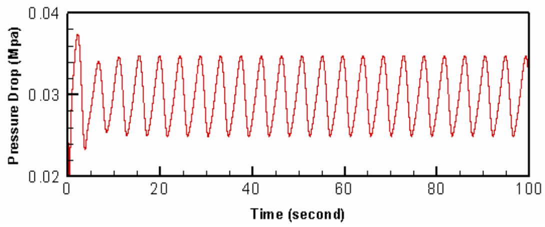
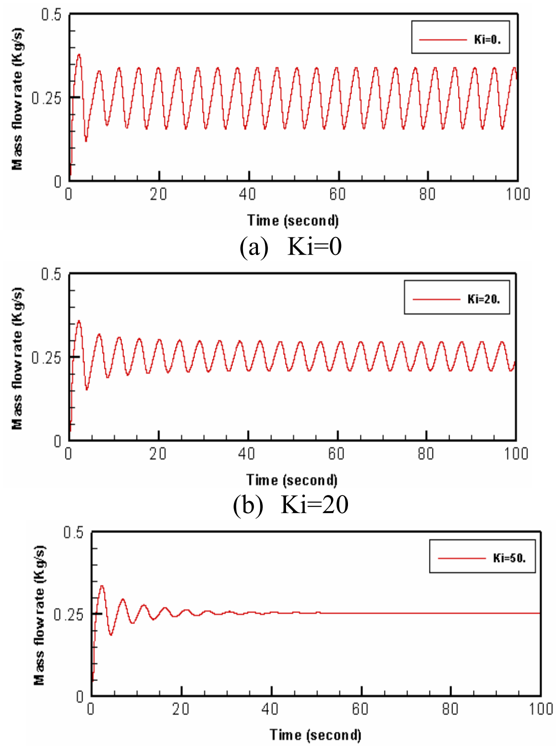



Fig.6 Temporal variation of pressure drop in a two-phase region




(a) Ki=0

(b) Ki=20

(c) Ki=50

Fig.7 Temporal variation of inlet flow rate according to throttling coefficient

Fig.5 and Fig.6 show the temporal oscillation of boiling boundary and pressure drop in the boiling region. Fig.7 shows the temporal variation of inlet flow rate according to the throttling coefficient. We can observe when Ki=0, the inlet mass flow rate oscillation is severe and when the throttling coefficient becomes larger, the amplitude of oscillation becomes smaller and when Ki=50, the oscillation disappears.

## 4. Conclusions

A simple method for analysis of the density wave two-phase instability in a liquid metal reactor S/G is proposed and the method is applied to the analysis of density wave instability in a 50MWt S/G at JAEA. The results show that the present method predicts accurate solutions and produces physically correct solutions. The present code can be used to determine the throttling coefficient for KALIMER-600 reactor.

## REFERENCES


[1] S. K. Choi, “Analysis of the Nonlinear Density Wave Two-Phase Instability in a Liquid Metal Reactor Steam Generator”, KAERI Internal Report,2005.

[2] J. Koubota, T. Tsuchiya, T. Iwashita and K. Monta, "Hydrodynamic Stability Tests and Analytical Model Development for Once-Through Sodium Heated Steam Generator," Boiler Dynamics and Control in Nuclear power Stations, London, 1979.